SAND TRANSPORT FORT DERUSSY BEACH

By

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1. PURPOSE:

Like most of the beach at Waikiki, the beach at Fort DeRussy has a history of erosion (U.S Army Corps of Engineers, 1987). The purpose of this study, therefore, is to find the reasons for erosion at this segment of shoreline and to locate the redeposited sand for better future management of this valuable resource.

2. INTRODUCTION:

Fort DeRussy beach is located adjacent to Waikiki Beach along the southern coast of the Island of Oahu, about 4.5 km east of downtown Honolulu, Hawaii (fig. 7). Replenishment of this sector of beach was authorized by the US Congress in 1965, House Document No. 104, 89th Congress, 1st Session. Prior to replenishment Fort DeRussy beach had been only 15 to 25 m wide (from the seawall) at its Diamond Head side and aerial photographs show little or no beach sand at the western end adjacent to the Hilton resort complex. The 1969 improvement project widened the beach to a width of 45 to 75 m and required 82,000 cu m of dredged coral and concrete debris to fill a dredged hole and low areas near the seawall. Unwashed crushed-coral sand was used to cover the fill (U.S Corps of Engineers, 1987). Although maintenance for the Fort DeRussy beach is a responsibility of the U.S Government and it serves US military personnel, the location of the beach in the heart of the tourist section of Hawaii makes it a major recreational area that attracts both tourists and local residents.

3. <u>OBJECTIVE:</u>

The present study addresses the problem of transport and redeposition of the beach sand and the feasibility of slowing the future rate of the sand loss from the beach. Specific objectives are:

(1) to describe the historical background of the beach,

(2) to identify the present and potential recreational uses,

(3) to describe sand now on the beach and where it is transported and deposited.

<u>HISTORICAL BACKGROUND</u>

Fort DeRussy was established as Waikiki Military Reservation in 1908 (renamaed in 1909) to provide coastal artillery defense for Honolulu Harbor and Pearl Harbor. Batteries Randolph and Dudley were completed in 1911 and massive 0.38 m and two smaller 0.16 m rifles, were installed in each. During World War II, Fort DeRussy played a significant role. It was used for seacoast defense, antiaircraft defense, a garrison for troops, military police headquaters, and a camouflage school. In 1942, the Fort DeRussy Recreation Center was opened with housing accommodations for enlisted personnel, and in 1949, the post was designated as the Armed Forces Recreation Center. Fort DeRussy remains a military recreational area, and is also serves as Headquarters of the US Army reserve units in Hawaii.

Battery Dudley was demolished in the late 1960s. Battery Randolph, which lies about 75 m inland of the seawall on the Diamond Head side of the beach, was listed on the National Register of Historic Places in 1984 as one element in the Artillery District of Honolulu. Other studies have revealed the presence of prehistoric and historic human burial site and artifacts along the shoreline and land adjacent to it, at the Halekulani Hotel site just east of Fort DeRussy, and also a few human burials on the Hale Koa Hotel site (U.S Army Corps of Engineers, 1987). The Hale Koa Hotel is a 14 story facility constructed in 1975 to house vacationing military personnel.

The 1969 improvment project widened the beach to 42 to 67 m wide, using 82,000 cu m of dredged coral material and concrete debris to fill the dredged hole and low areas against the seawall. Unwashed crushed coral sand was used to cover the fill. The exxisting beach is entirely artificial fill, composed of a mixture of coralline fragments and beach sand fines, a product of the restoration project carried out in 1976. The constant erosion has already resulted in one beach restoration (maintenance) project in 1981. Beach restoration is only a maintenance measure and will not provide a permanent solution to the problem (erosion) at the Fort DeRussy beach. Portions of the original shoreline might possibly be found landward about 16 to 23 m of fill close to the seawall (U.S Army Corps of Engineers, 1987).

PRESENT AND POTENTIAL RECREATIONAL USES

The strand is part of Fort DeRussy Beach Park, which attracts sunbathers, swimmers, snorkelers, shoreline fishermen and a limited amount of controlled nearshore boating activities. It is designed as the Fort DeRussy Beach Park. There is no vegetation on the beach area itself. Vegetation inland of the project area consists of predominately cultivated ornamental plants. According to the Bird and Mammal survey of Army lands in Hawaii, the highly urbanized environment of Fort DeRussy and surrounding lands provide considerable habitat for for exotic bird life, such as the house sparrow, common mynah, and various species of dove (Shallenberger, 1977). Mice and some species of rats are also present. The Hilton Hawaiian Village complex of hotels and shops lies on the Honolulu (north-west) side of the beach. A 47 m long pier, owned by the State but controlled by the hotel, acts as the western boundary to the Fort DeRussy Beach. The eastern border of Fort DeRussy is the Waikiki Shores Apartment and a 66 m long rock groin which partially protects a City and County owned storm drain box culvert. Large basalt of boulders are placed along to the western side of the groin. Coral pebbles and cobbles armor the foreshore to the west of the groin. The Halekulani sand channel is located to the east of the groin and may serve as a conduit to move seaward toward the open ocean. A preliminary study survey, conducted by U.S Army Corps of

Engineers found that on weekends in April 1987, beach-goers avoided rocky portions of the beach. The rockiest zone is a 7 to 9 m wide band just west of the groin. In contrast, the eastern side of the groin is devoid of coral fragments, pebbles, cobbles and boulders.

The use of the beach area at Fort DeRussy was addressed in a previous study completed for the Department of Geography in Fall 1987 (Rouf, 1987). That study found that on an average weekend, there are approximately 1 individual per square meter. Most of the beach users lie on the sandy, comfortable beach surface area and avoid areas covered by coarse coral sand and pebbles. Similarly, most beach-goers preferred to swim or to walk on sandy areas devoid of coral pebbles. That study recommended expansion of the useable beach surface and swimming area by removal of all coral fragments or by covering the coral fragments with more sand.

METHODS:

Eight samples of dry beach sand were collected approximately 100 m a part along the berm crest of the beach by hand-filling bottles.

Standard methods of grain-size analysis with nested sieves were used for the sediment analysis at Hawaii Institute of

Geophysics. Samples were spilt into half and 60 to 100 gm were weighed and put into the stack of sieves which were then shaken in a Ro-Tap machine for 10 minutes. The amount of sediment accumulated on each sieve was weighed and the cumulative percentages calculated. These data were then plotted on a graph of particle diameter verses cumulative percentage, and smooth curves drawn through the data points. The values necessary to calculate statistical parameters that describe the sediment were then picked off these curves (Folk, 1968).

RESULTS

Mode

Values of mode were taken from sieve analysis sheet as the largest weight percent in any single half-phi interval. The sieve analysis shows that the mode for these eight beach samples varies from 1.00 phi through 2.00 phi (table 1 and fig. 1). Samples 8, 9 and 10 from the eastern part of the beach are finer than those from the rest of the beach.

Median

Values of median were calculated graphically according to the diameter corresponding to the 50% mark on the cumulative curve. The median for these eight beach samples varies from 0.70 phi through 1.60 phi (table 1 and fig. 2). Samples 1, 2, 3 and 15 are coarsest and samples 17, 8, 9 and 10 are finer.

Mean

Values of mean were calculated graphically according to the formula: $Mz=(\phi16+\phi50+\phi84)/3$ (Folk, 1968). The mean for these eight samples varies from -0.366 phi through 1.533 phi (table 1 and fig. 3). Sample 10 is the finest and 3 is the coarsest. Samples 9, 10, 8 and 17 are finer than rest of the samples.

Standard Deviation

Values of standard deviation were calculated graphically according to the formula: $S.D. =(\phi84-\phi16)/4 + (\phi95-\phi5)/6.6$. This statistic indicates the degree of sorting of the sand grains.

Sand at Fort DeRussy beach falls with in the range of moderately well sorted (0.50-0.710 ϕ), moderately sorted (0.71-1.00 ϕ) and poorly sorted (1.0-2.00 ϕ) (Folk, 1968). Samples 10, 9, 15 and 17 are moderately well sorted, samples 1, 2, and 8 are moderately sorted; only sample 3 is poorly sorted.

Skewness

Skewness was calculated graphically according to the formula: $Sk= (\phi16+\phi84-2050)/(\phi84-\phi16)$. Skewness, a unitless quantity, is a measure of the departure of actual grain size distribution from a curve symmetric about the mean. A symmetric curve has a skewness of 0.00. Positively skewed distributions have excess amounts of fine grains, that is the frequencey curve has a tail towards the fines and negative values of skewness indicate a coarse tail.

Samples 2, 3 and 15 are positive skewed, indicating that these samples have particle-size distributions with fine tails. Samples 1, 17, 8, 9 and 10 have negative tails.

Kurtosis

Kurtosis, like skewness, is measured relative to a normal Gaussian, bell-shaped probability curve.

"It measures the ratio between the sorting of the 'tail' of the curve and the sorting in the central portion. If the central portion is better sorted than the tail, the curve is said to be excessively peaked or leptokurtic; if the tails are better sorted than the central portion, the curve is deficiently of flat-peaked and plyaykurtic" (Folk, 1968).

Kurtosis is calculated graphically from the formula:

$$K=(\phi 95-\phi 5)/2.44(\phi 75-\phi 25)$$ (Folk,1968).

Platykurtic distributions have values less than 1.00 ϕ while those of leptokurtic curves exceed 1.00 ϕ. At Fort DeRussy, samples 1, 2, 3, 17, 8 and 9 has value more than 1; only samples 15 and 10 have values less than 1.

SUMMARY OF ATTRIBUTES OF PARTICLE-SIZE DISTRIBUTIONS OF FORT DERUSSY BEACH

The visual observations along Fort DeRussy Beach in early summer of 1988 show that the 30 to 100 m wide and 576 m long beach along Fort DeRussy is composed of white sand and crushed coral.

As expressed by the mode, median and mean, the sand to the east in front of the Halekulani Hotel is finer than the sand from Fort DeRussy beach. The probable reason for the relatively fine size is the low wave energy typical of this area. As mentioned earlier, Fort DeRussy beach is subject to constant wave and tidal erosion as well as heavy use by military personnel, their families and the general public (U.S Army Corps of Engineers, 1987). Small to large rock and coral chunks continue to become exposed from underlying fill as the finer fraction is removed. This area is heavily used by the beach goers, and small volumes of sand are removed by beach-goers wet feet with a larger portion removed through the Halekulani Sand Channel. As a result, the beach surface at some locations and much of the wading and swimming area are uncomfortable upon which to lie or walk.

The standard deviation for the beach varies from 0.522 phi to 1.415 phi. Most of the beach sand is moderately well sorted except a small area of very poorly sorting due to a few large coral fragments collected in sample number 3.

Sand samples 17, 8, 9 and 10, located along the eastern part of the study area, are negatively skewed. Therefore, this beach segment may have a few relatively large (coarse) grains but probably no very fine silt or clay. Milky-white waters were observed along the shoreline during summer weekends of 1988 and are probably characteristic of the area. Probably, the finer grains are transported seaward into the ocean and winnowed from the beach. On the other hand, samples collected from the western portion of Fort DeRussy beach, samples 2, 3 and 15 are positively skewed. Therefore, in these areas expect to find mostly medium to fine-grained sands, some very fine sand and coarse silt but probably no coral pebbles.

Probably a small portion of the sand is removed by the beach-goers with a much larger portion removed through the Halekulani Sand Channel. This sand channel is situated on the eastern end of the study area, right across from the Halekulani Hotel on the ocean side and extended seaward. During the high tides sands from Fort DeRussy beach wash across the groin to the beach cell at the Reef Hotel to the east and later these sands gradually move toward the ocean through this channel.

This project was a very educational one. I devoted more time than I anticipated. I want to thank Dr. William Coulbourn, project monitor, for his constructive guidance. Each meeting with him was an educational one. I also thank him for letting me use the Sedimentology lab at Hawaii Institute of Geophysics. I want to thank Dr. Sherwood Maynard for getting the necessary supplies and funding for the project.

This project was the most valuable and educational experience in my entire undergraduate career. It helped me to see how a scientific paper should be prepared and written. I always wanted to learn how the geological shoreline works. Through this project gained knowledge in the geological shoreline process which I plan to use in the future.

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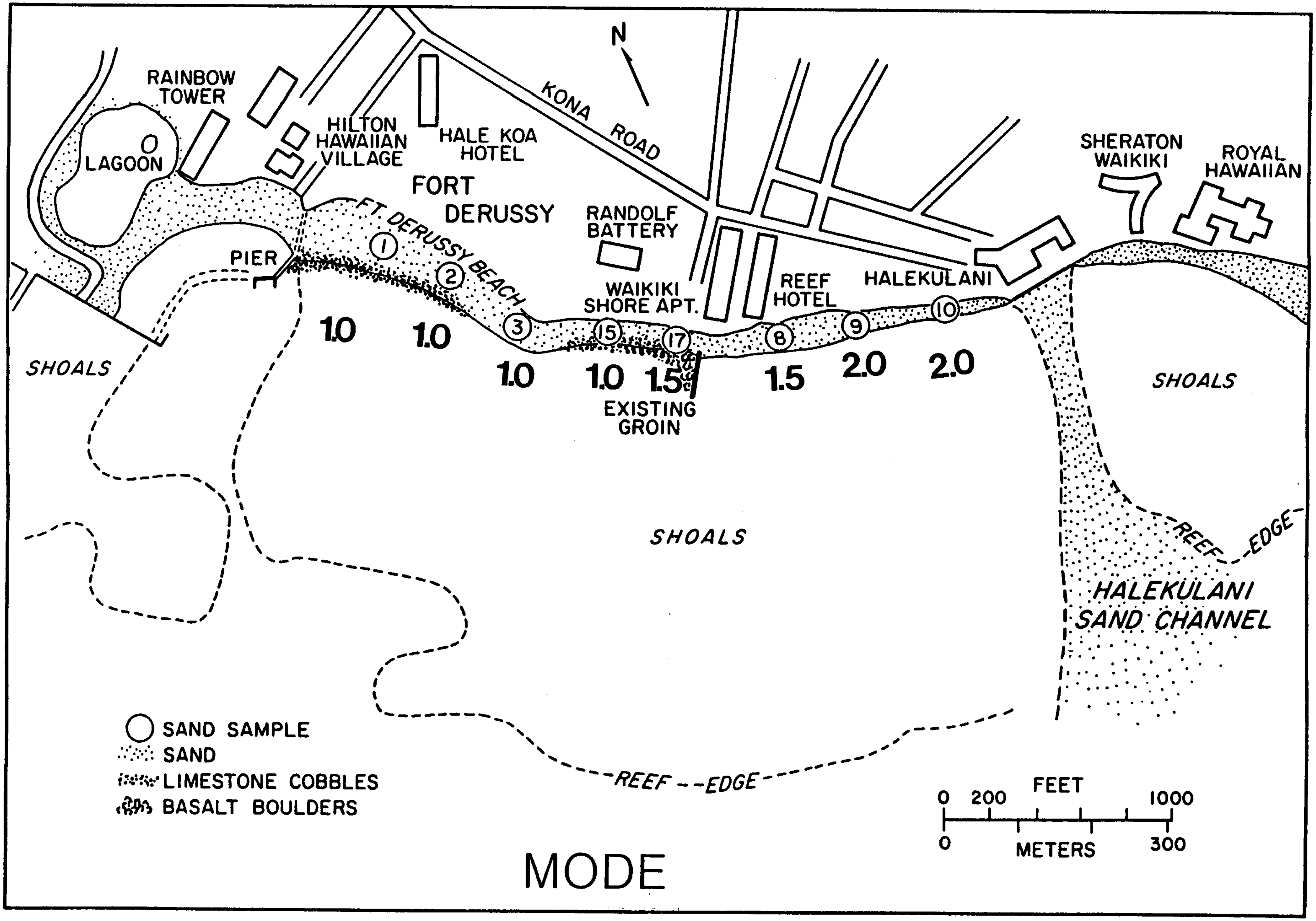
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Figure 1

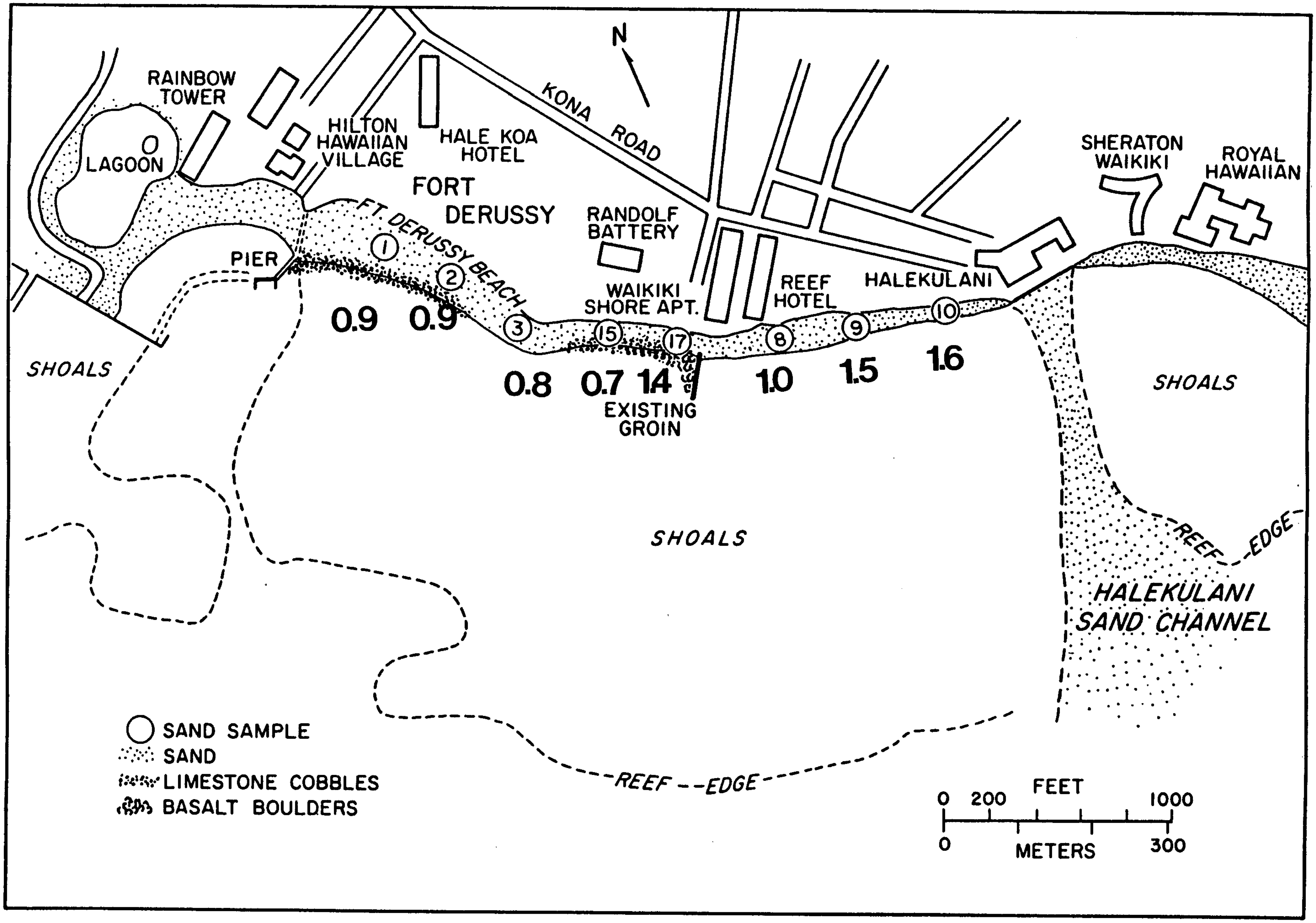
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Figure 2

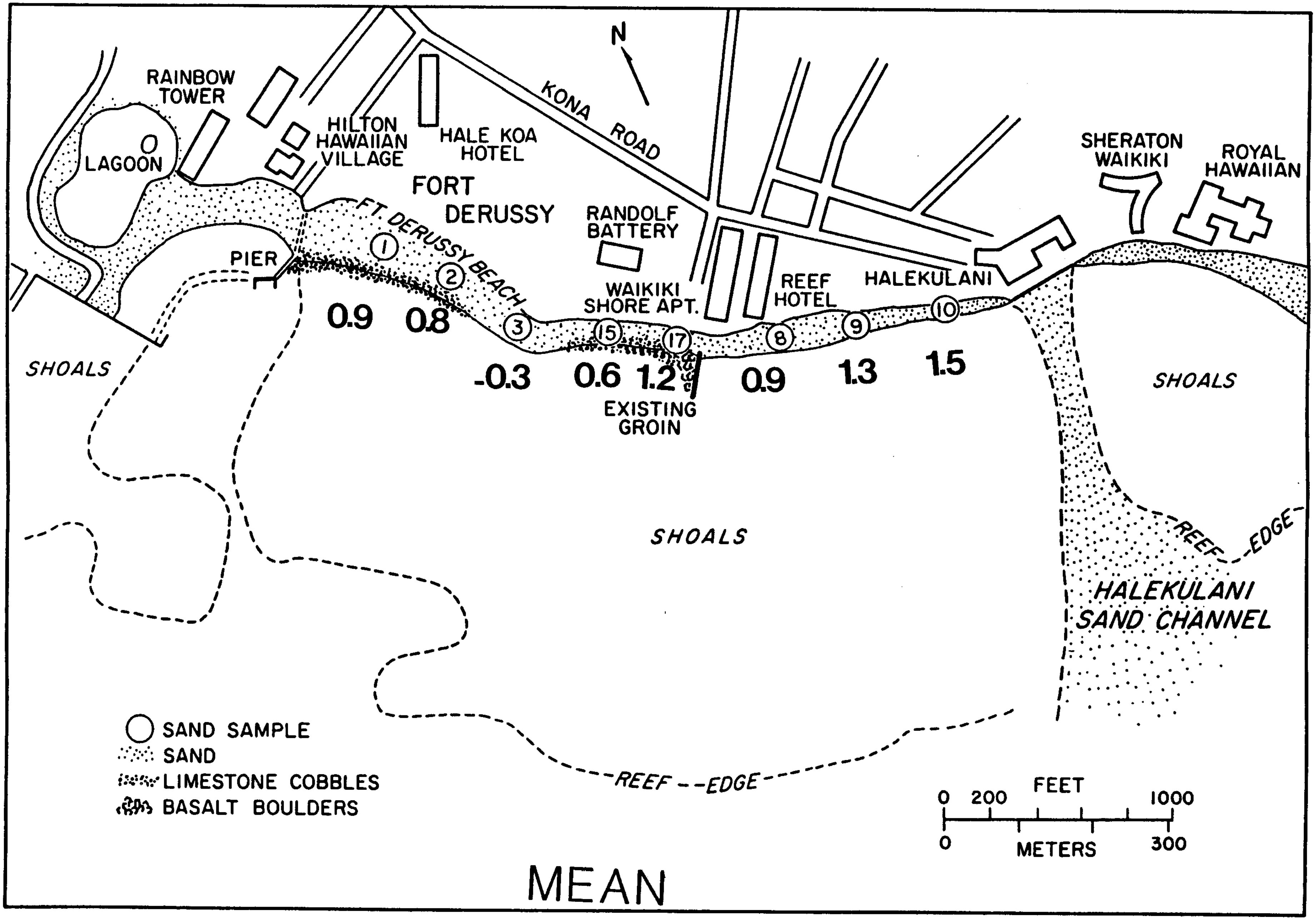
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Figure 3

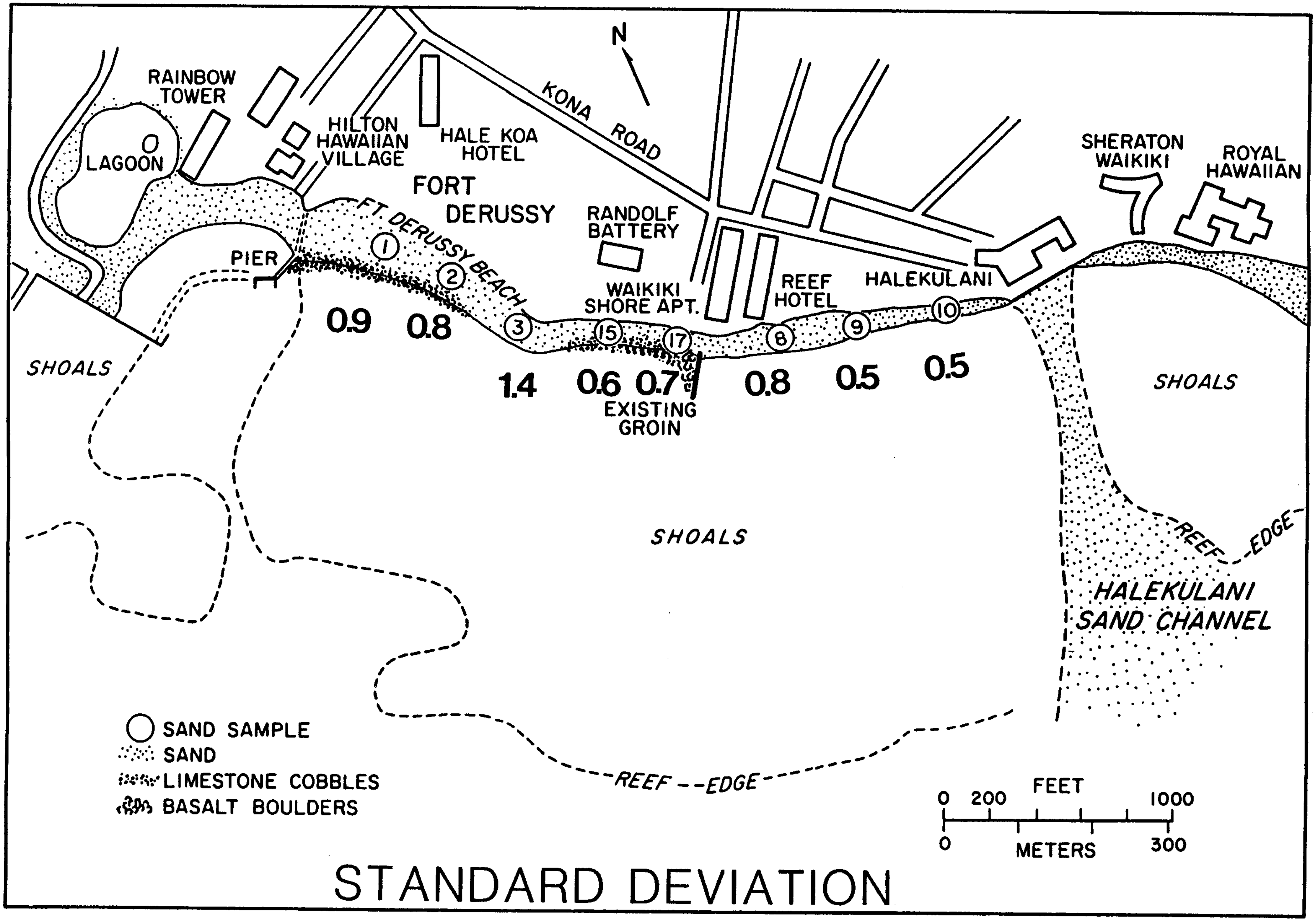

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Figure 4

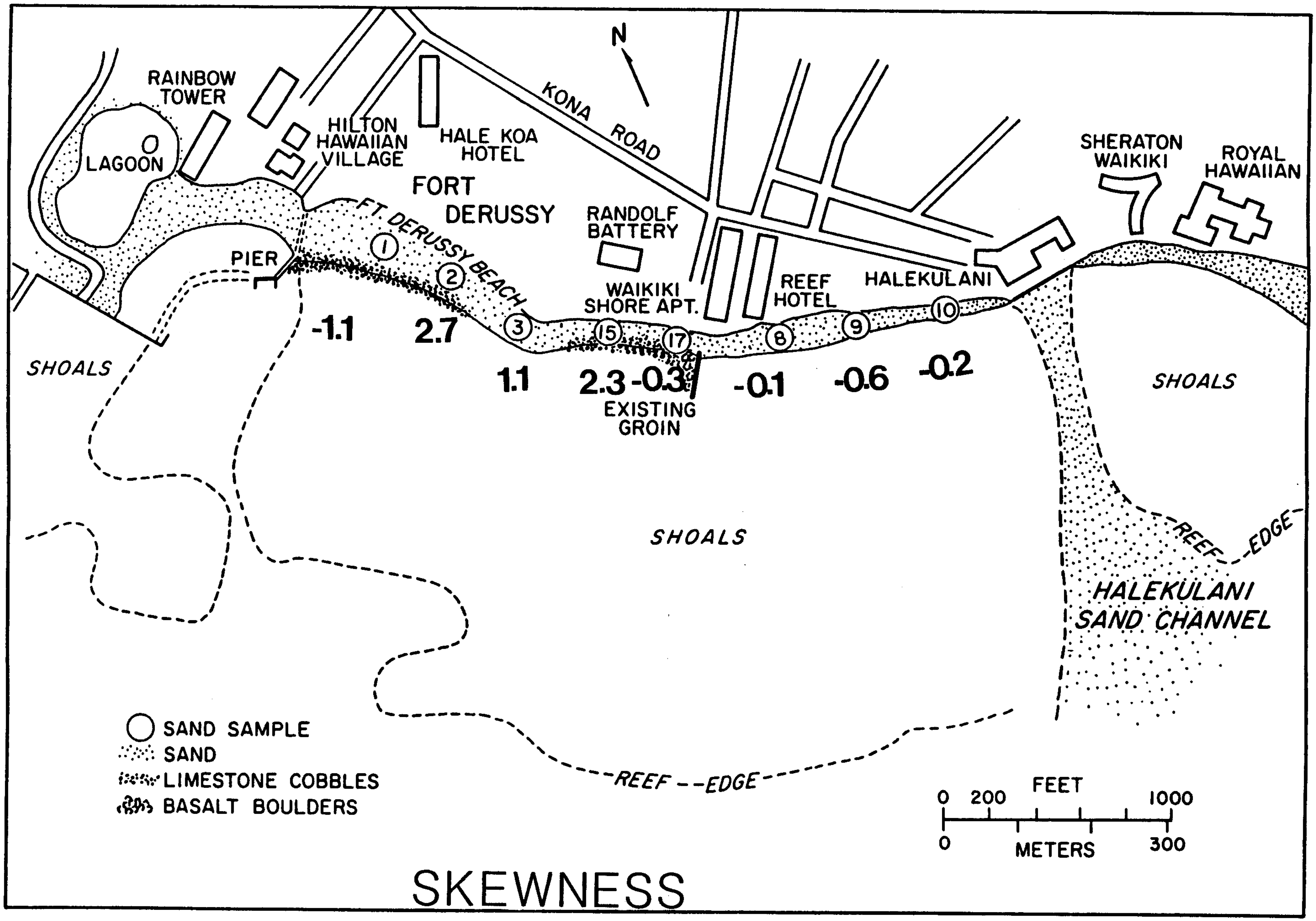
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Figure 5

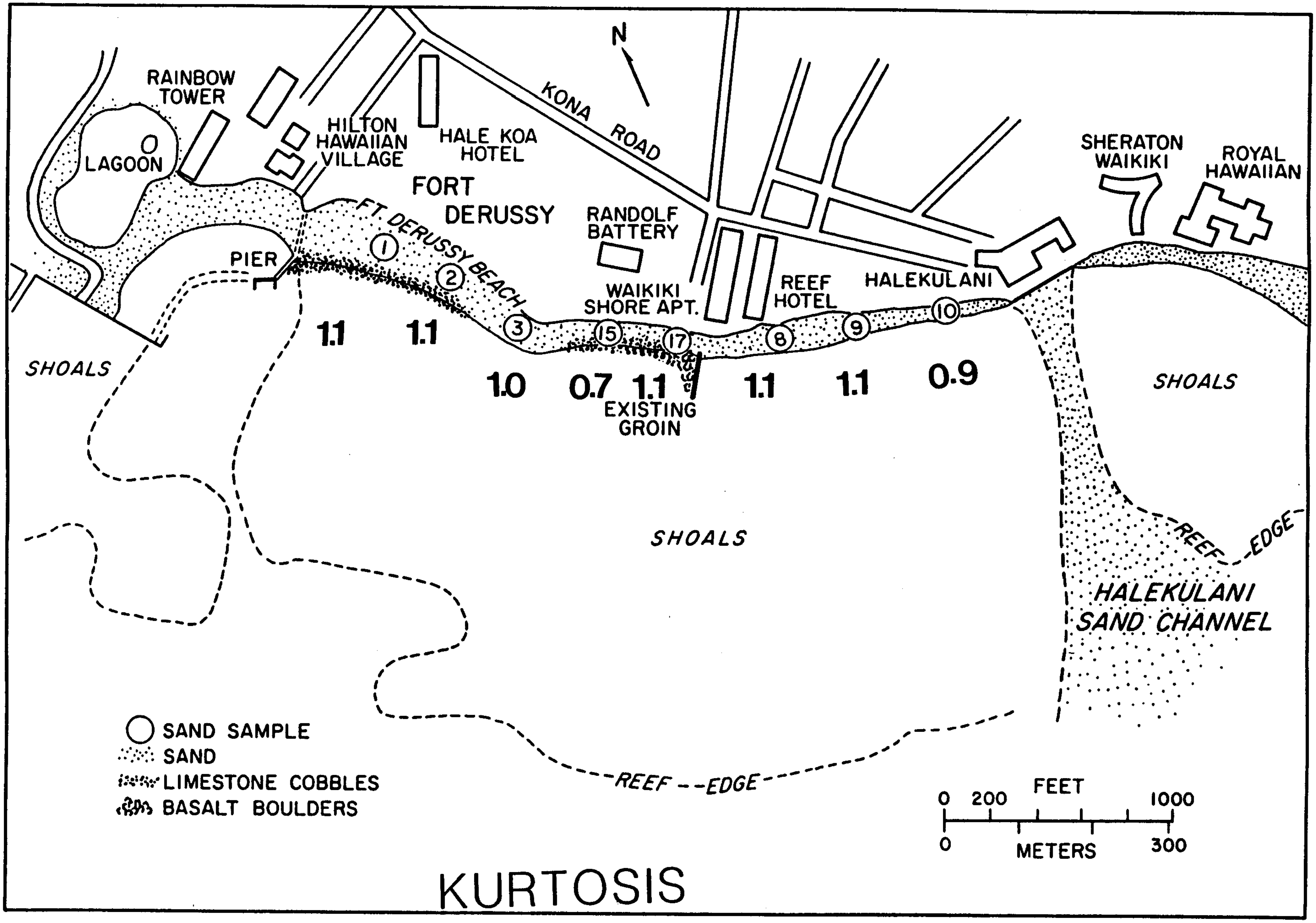
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Figure 6

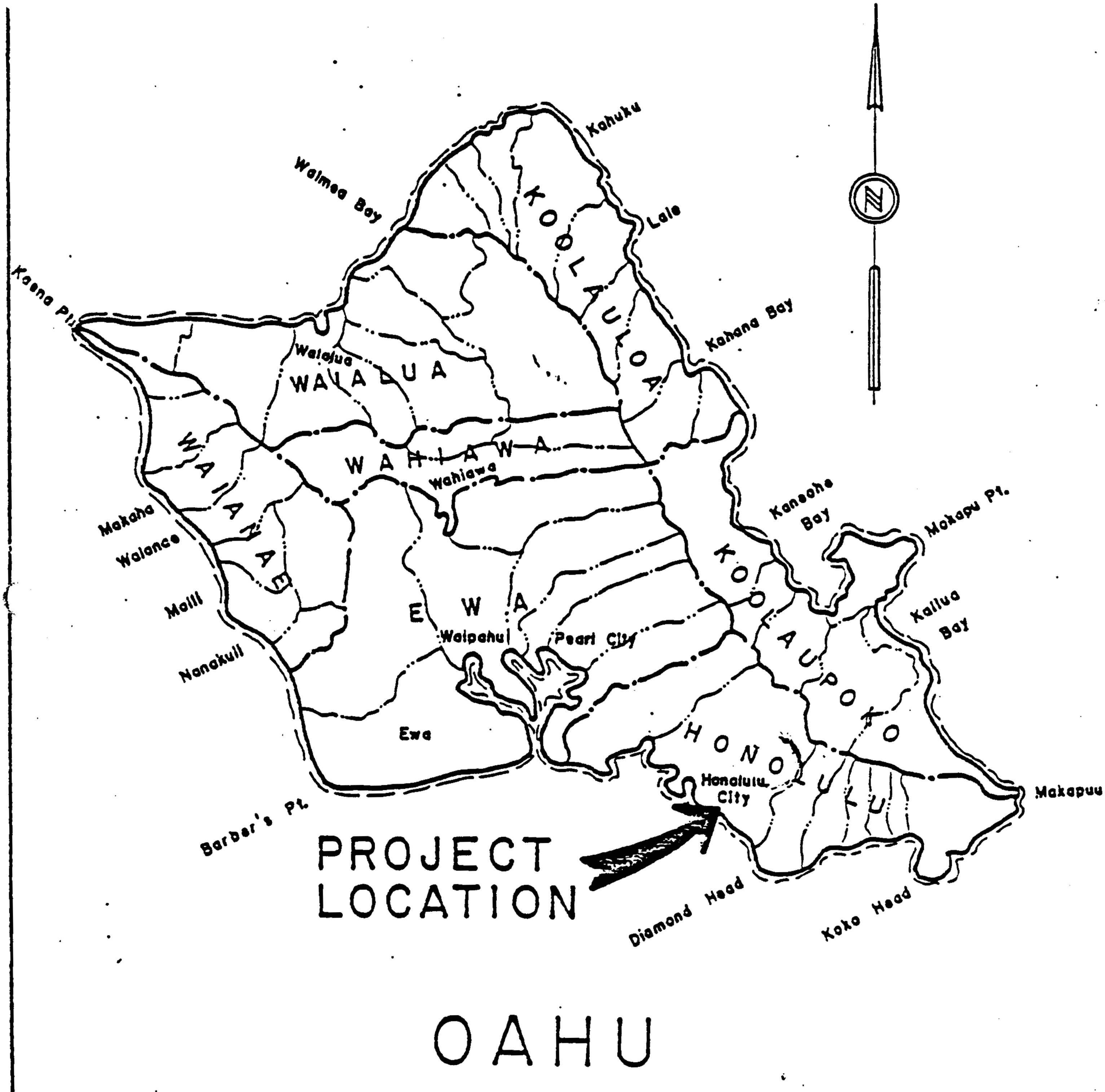

FIGURE 7

LOCATION MAP

Table 1

STATISTICAL TABLE

SAMPLE	MODE	MEDIAN	MEAN	S.D	SKEWNESS	KURTOSIS
1	1.0	0.9	0.966	0.905	-1.137	1.065
2	1.0	0.9	0.866	0.818	2.692	1.145
3	1.0	0.8	-0.366	1.415	1.086	1.065
15	1.0	0.7	0.600	0.638	2.272	0.702
17	1.5	1.4	1.266	0.713	-0.285	1.093
8	1.5	1.0	0.933	0.809	-0.125	1.135
9	2.0	1.5	1.300	0.522	-0.600	1.053
10	2.0	1.6	1.533	0.507	-0.200	0.870

Tw = 116.19

B[illegible] = 40.35

76.64

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 1 DATE: 4-13-87

LOCALITY : [illegible] ANALYST: [illegible]

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	[illegible]	0.77	0.57	0.77
2.83	-1.5	0.27	0.35	0 84	1.12
2.00	-1.0	0.51	0.67	1.35	1.79
1.41	-0.5	1.20	1.57	2.55	3.36
1.00	0.0	4.73	6.19	7.28	9.55
0.71	+0.5	11.[illegible]	15.15	18.86	24.7
0.50	+1.0	21.00	27.47	39.86	52.17
0.35	+1.5	21.00	27.47	60.86	79.64
0.25	+2.0	11.00	14.39	71.86	94.03
0.18	+2.5	2.20	2.88	74.06	96.91
0.13	+3.0	0.00	00	74.06	96.91
0.09	+3.5	1.65	2.16	75.71	99.07
0.06	+4.0	0.60	0.79	76.31	99.86
PAN		0.15	0.20	76.46	100 6
TOTAL		76.46	100.06	76.46	100.6

77.06

1

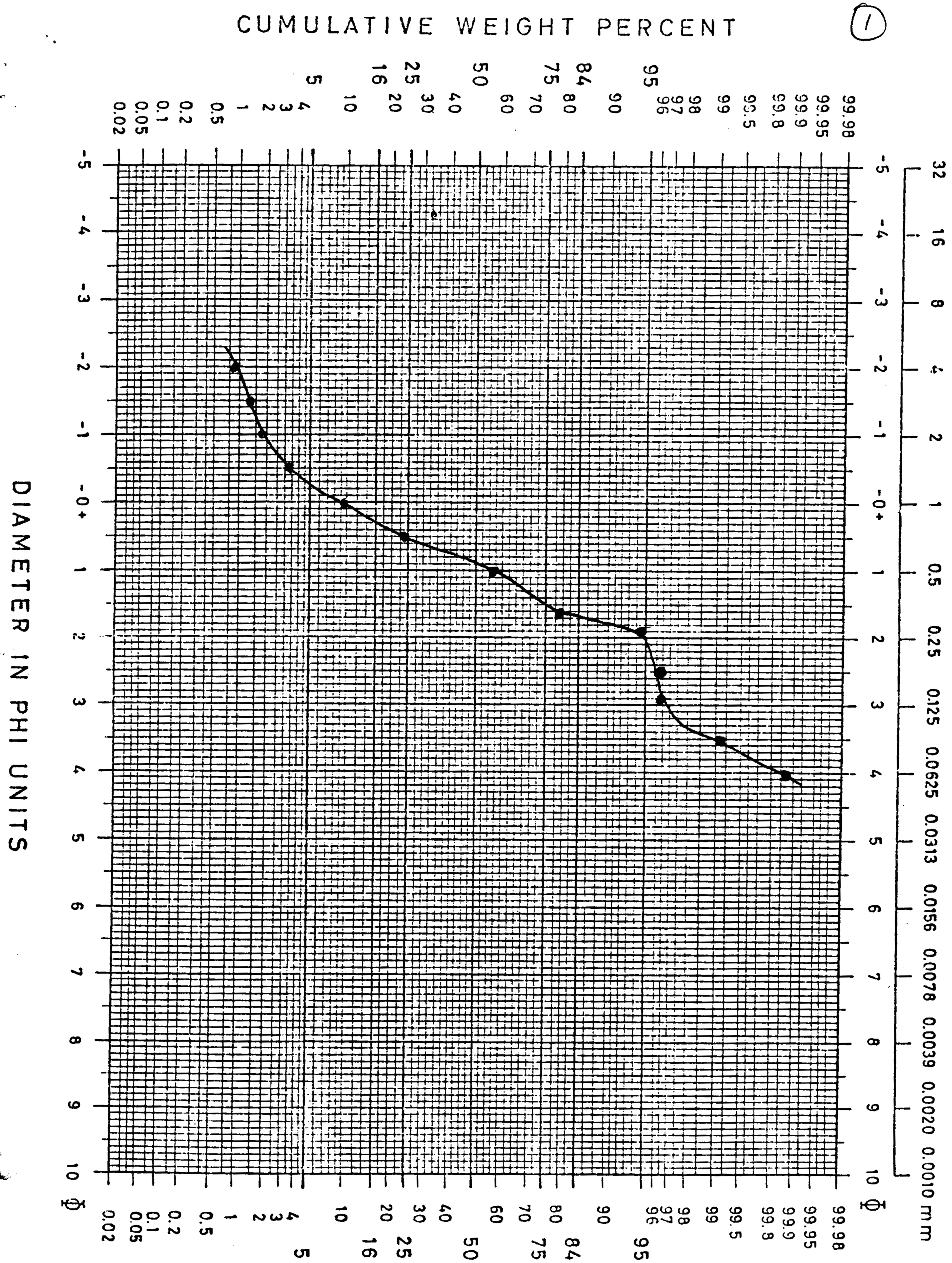

Diagram I

TW = 89.53

Baker = 22.17

Sample weight = 67.56

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 2
LOCALITY : 46

DATE: 5/25/88
ANALYST: Muhammad [illegible]

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	0.48	0.71	0.48	0.71
2.83	-1.5	0.37	0.54	0.85	1.25
2.00	-1.0	0.20	0.30	1.05	1.55
1.41	-0.5	1.50	2.22	2.55	3.77
1.00	0.0	4.29	6.35	6.84	10.12
0.71	+0.5	12.07	17.88	18.91	28
0.50	+1.0	20.61	30.53	39.52	58.53
0.35	+1.5	18.09	26.8	57.61	85.33
0.25	+2.0	6.96	10.31	64.57	95.64
0.18	+2.5	1.87	2.77	66.44	98.41
0.13	+3.0	0.62	0.918	67.06	99.32
0.09	+3.5	0.20	0.296	67.26	99.62
0.06	+4.0	0.12	0.177	67.38	99.80
PAN		0.12	0.177	67.5	99.78
TOTAL		50	99.97	67.5	99.78

2

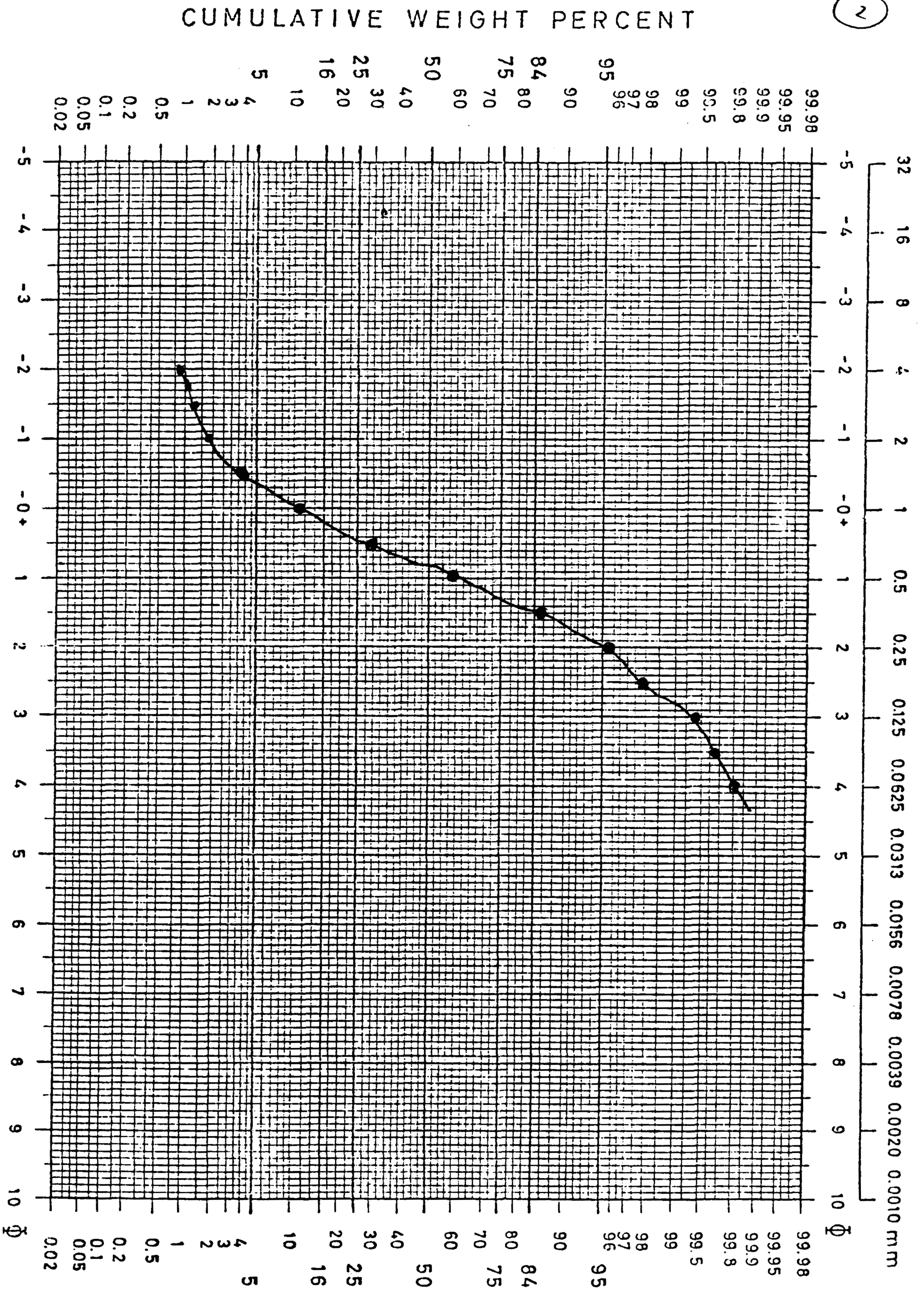
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS
0.02 0.05 0.1 0.2 0.5 1 2 3 4 5 10 16 20 25 30 40 50 60 70 75 80 84 90 95 96 97 98 99 99.5 99.8 99.9 99.95 99.98
-5 -4 -3 -2 -1 -0+ 1 2 3 4 5 6 7 8 9 10 Φ
32 16 8 4 2 1 0.5 0.25 0.125 0.0625 0.0313 0.0156 0.0078 0.0039 0.0020 0.0010 mm

Diagram I

Beaker = 41.724
Sample weight = 95.66 g

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 3
LOCALITY : HG

DATE: 4/13/88
ANALYST: [illegible]

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum. %
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	6.60	6.90	6.60	6.90
2.83	-1.5	0.64	0.66	7.24	7.56
2.00	-1.0	1.97	2.06	9.21	9.62
1.41	-0.5	3.93	4.11	13.14	13.73
1.00	0.0	4.97	5.19	18.11	18.92
0.71	+0.5	15.98	16.71	34.09	35.63
0.50	+1.0	25.90	27.08	59.99	62.71
0.35	+1.5	21.80	22.79	81.79	85.5
0.25	+2.0	9.95	10.40	91.74	95.9
0.18	+2.5	2.53	2.64	94.27	98.54
0.13	+3.0	0.95	0.99	95.22	99.53
0.09	+3.5	0.05	0.05	95.27	99.58
0.06	+4.0	0.20	0.20	95.47	99.78
PAN		0.15	0.15	95.62	99.93
TOTAL		95.62	99.93	95.62	99.93

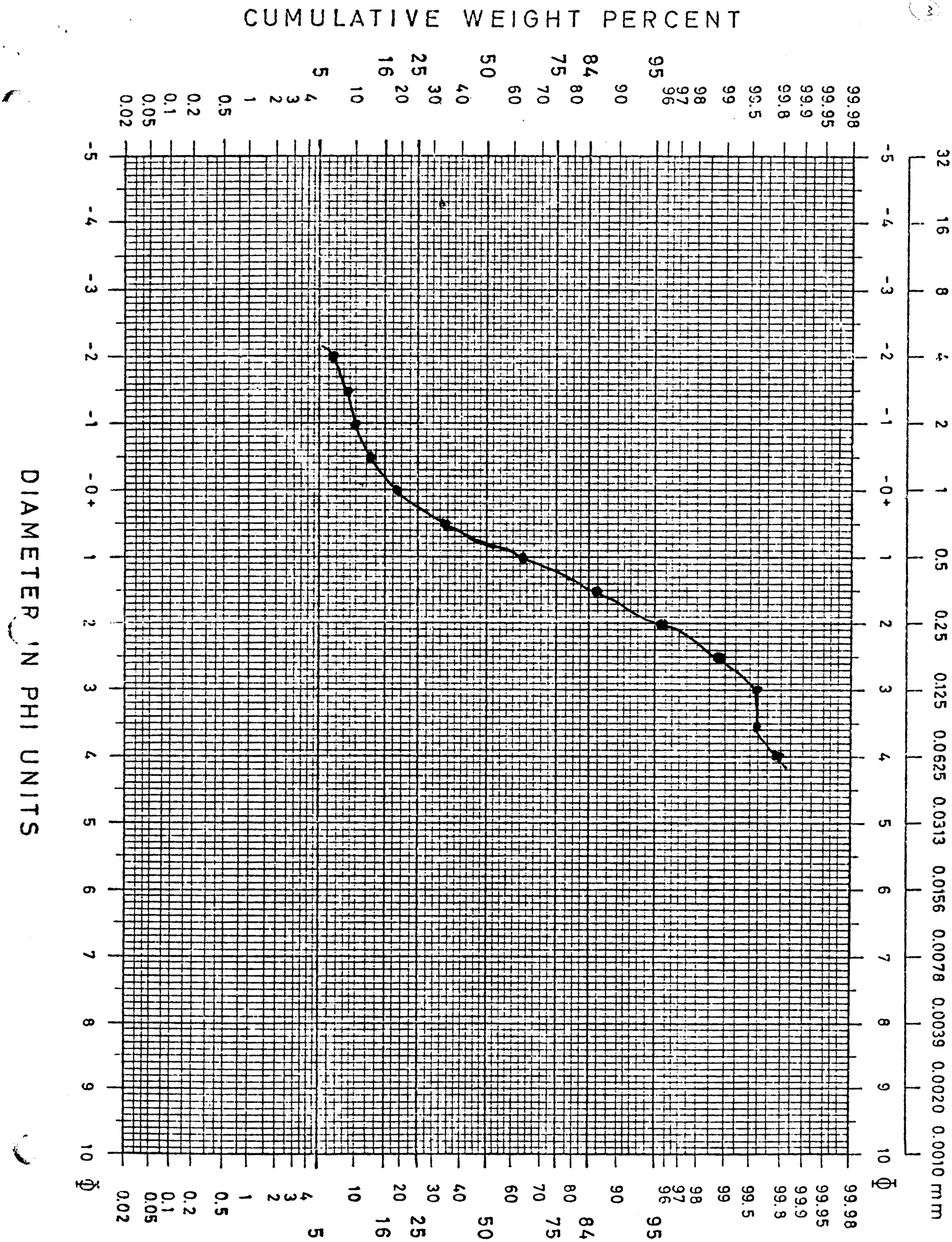

Diagram I

Tw = 91.57
B:ker = 22.17
sample = 69.4

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 15
LOCALITY :

DATE:
ANALYST:

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	2.07	3.08	2.07	3.08
2.83	-1.5	0.82	1.22	2.89	4.3
2.00	-1.0	0.971	1.44	3.86	5.74
1.41	-0.5	1.773	2.64	5.634	8.38
1.00	0.0	4.07	6.06	9.70	14.44
0.71	+0.5	14.20	21.17	23.90	35.61
0.50	+1.0	23.54	35.09	47.44	70.7
0.35	+1.5	17.41	25.95	64.85	96.65
0.25	+2.0	0.61	0.90	65.46	97.55
0.18	+2.5	1.13	1.68	66.59	99.23
0.13	+3.0	0.31	0.46	66.90	99.69
0.09	+3.5	0.08	0.11	66.98	99.8
0.06	+4.0	0.04	0.05	67.02	99.85
PAN		0.04	0.05	67.06	99.9
TOTAL		67.07	99.9	67.06	99.9

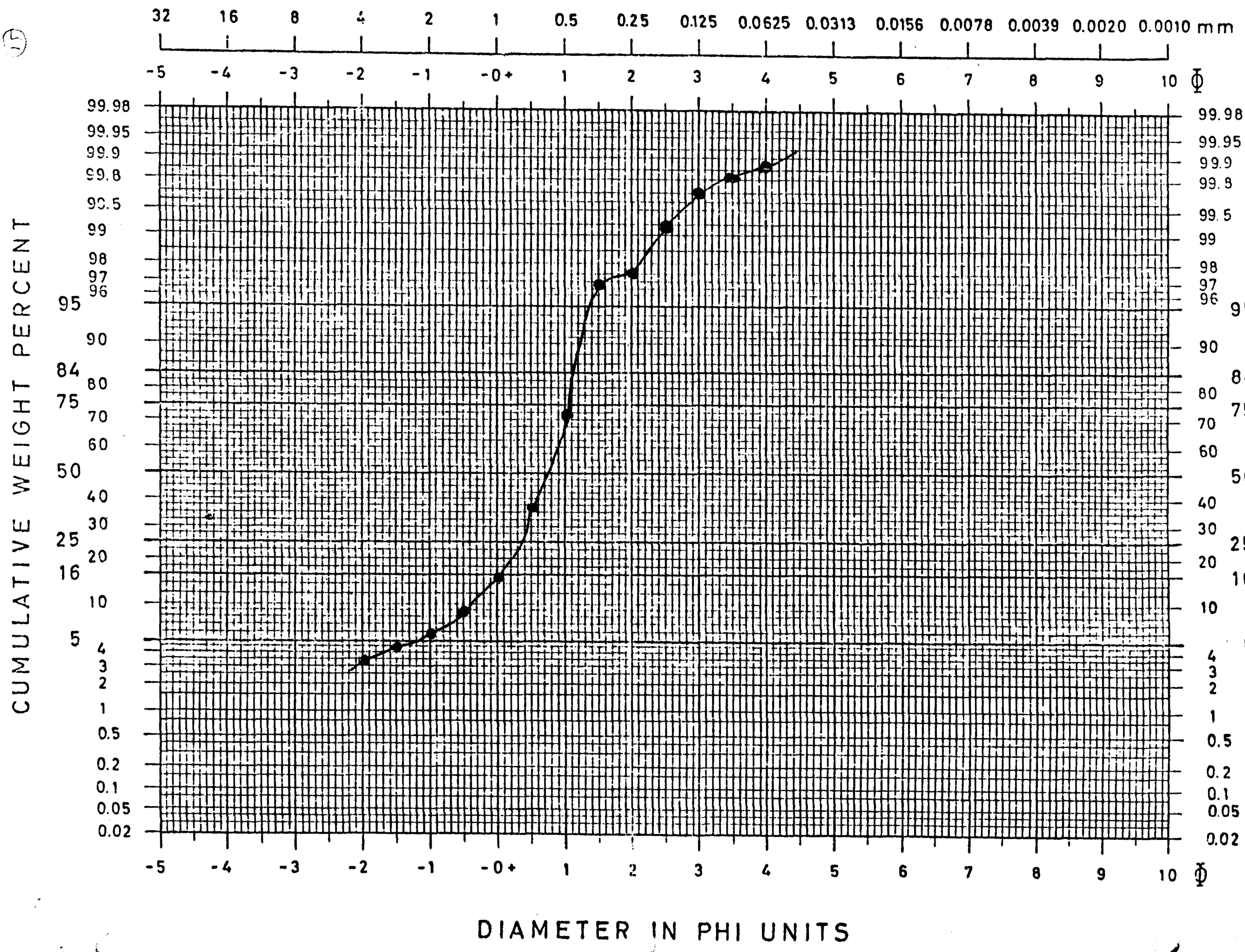
32 16 8 4 2 1 0.5 0.25 0.125 0.0625 0.0313 0.0156 0.0078 0.0039 0.0020 0.0010 mm
-5 -4 -3 -2 -1 -0+ 1 2 3 4 5 6 7 8 9 10 Φ
CUMULATIVE WEIGHT PERCENT
99.98 99.95 99.9 99.8 99.5 99 98 97 96 95 90 84 80 75 70 60 50 40 30 25 20 16 10 5 4 3 2 1 0.5 0.2 0.1 0.05 0.02
DIAMETER IN PHI UNITS

Diagram I

TW = 107.78
- Biker = 22.17
Sample weight = 85.61

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 17
LOCALITY : HG

DATE: 5/26/88
ANALYST: Mohammad Rouf

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	8.20	10.07	8.20	10.07
2.83	-1.5	0.23	0.27	8.43	10.34
2.00	-1.0	0.27	0.32	8.7	10.66
1.41	-0.5	0.34	0.40	9.04	11.06
1.00	0.0	1.25	1.48	10.29	12.54
0.71	+0.5	4.19	4.95	14.48	17.49
0.50	+1.0	11.90	14.07	26.38	31.56
0.35	+1.5	24.14	28.54	50.52	60.1
0.25	+2.0	23.46	27.74	73.98	87.84
0.18	+2.5	8.65	10.46	82.83	98.3
0.13	+3.0	1.56	1.84	84.39	100.14
0.09	+3.5	0.13	0.15	84.52	100.29
0.06	+4.0	0.04	0.04	84.56	100.33
PAN		0.01	0.01	84.57	100.34
TOTAL		84.57	100.34	84.57	100.34

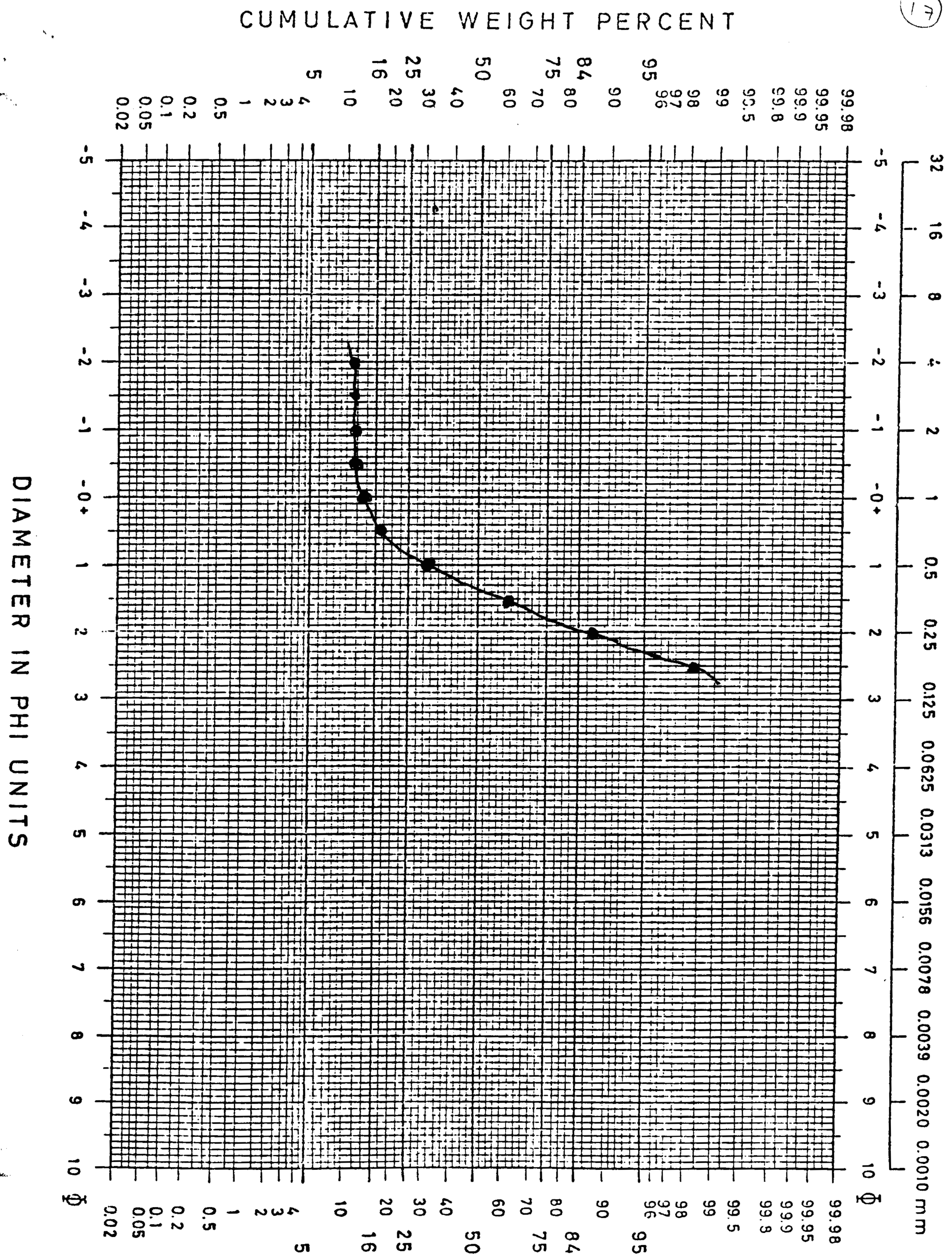

Diagram I

Total weight = 119.51
B. Ker = 22.17
Sample wt = 97.34

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 8
LOCALITY : HiG

DATE: 5'26'85
ANALYST: M. Rout

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	0.24	.24	0.24	.24
2.83	-1.5	0.36	0.37	0.60	.61
2.00	-1.0	0.51	0.53	1.11	1.14
1.41	-0.5	1.81	1.88	2.92	3.02
1.00	0.0	6.52	6.76	9.44	9.78
0.71	+0.5	17.38	18.00	26.82	27.78
0.50	+1.0	21.52	22.30	48.34	50.08
0.35	+1.5	24.67	25.56	73.01	76.64
0.25	+2.0	19.73	20.44	92.74	96.08
0.18	+2.5	3.54	3.67	96.28	99.75
0.13	+3.0	0.17	0.18	96.45	99.93
0.09	+3.5	0.04	0.04	96.49	99.97
0.06	+4.0	0.02	0.02	96.51	99.99
PAN		0.01	0.01	96.52	100
TOTAL		96.52	100	96.52	100

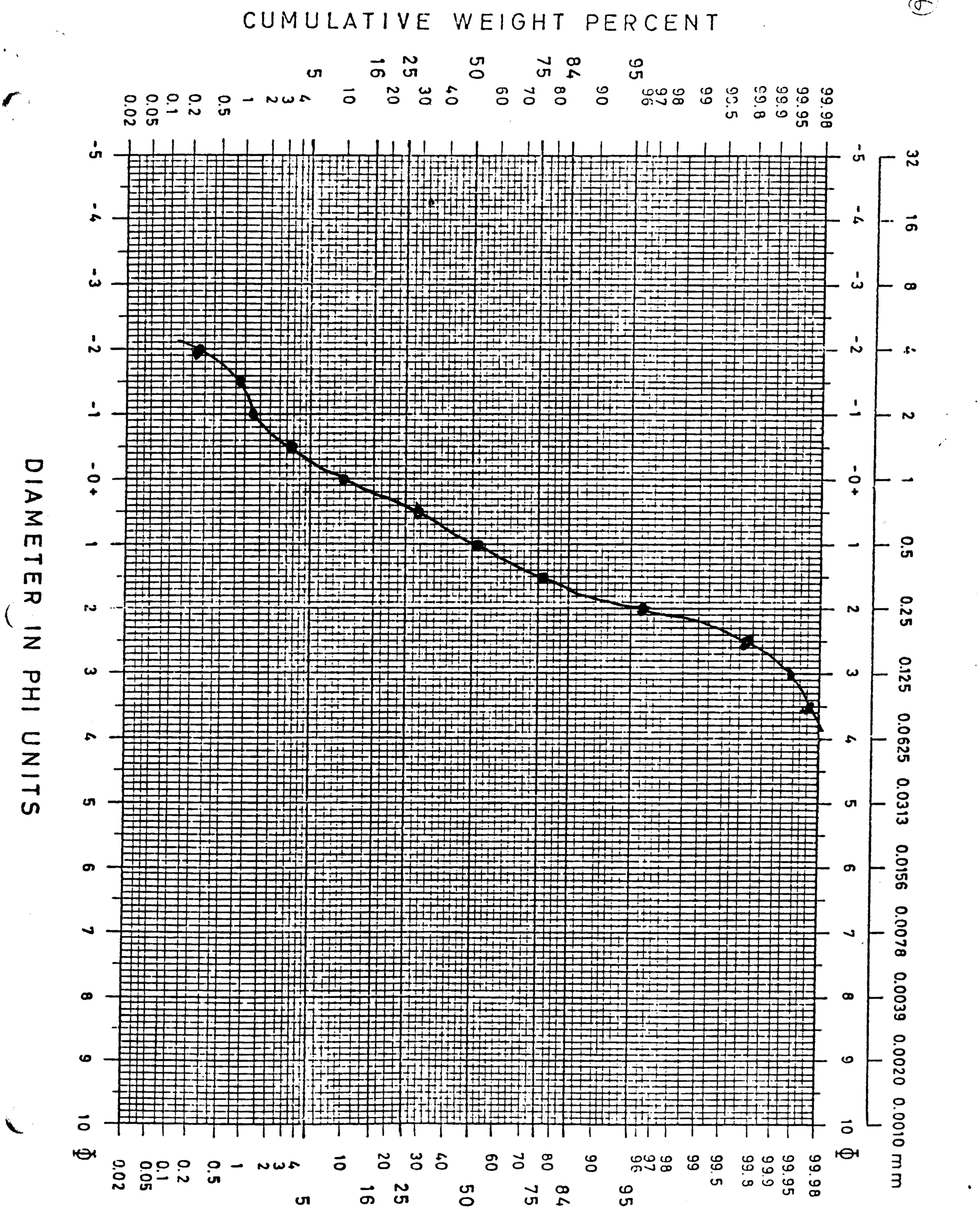

Diagram I

IW - 1-1.47

Biker = 22.17

Sample weight = 106.57

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 9　　　　DATE: 5/31/78

LOCALITY :　　　　ANALYST: M. Rouf

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	1.39	1.32	1.39	1.32
2.83	-1.5	0.03	0.03	1.42	1.35
2.00	-1.0	0.30	0.29	1.72	1.64
1.41	-0.5	0.60	0.57	2.32	2.21
1.00	0.0	2.32	2.21	4.64	4.42
0.71	+0.5	7.07	6.73	11.71	11.15
0.50	+1.0	14.90	14.17	26.61	25.32
0.35	+1.5	27.47	26.13	54.08	51.45
0.25	+2.0	51.35	47.90	104.43	99.35
0.18	+2.5	0.0	0	104.43	99.35
0.13	+3.0	0.41	0.39	104.84	99.74
0.09	+3.5	0.05	0.05	104.89	99.79
0.06	+4.0	0.03	0.03	104.92	99.82
PAN		0.02	0.02	104.94	99.84
TOTAL		12	99.84	104.94	99.84

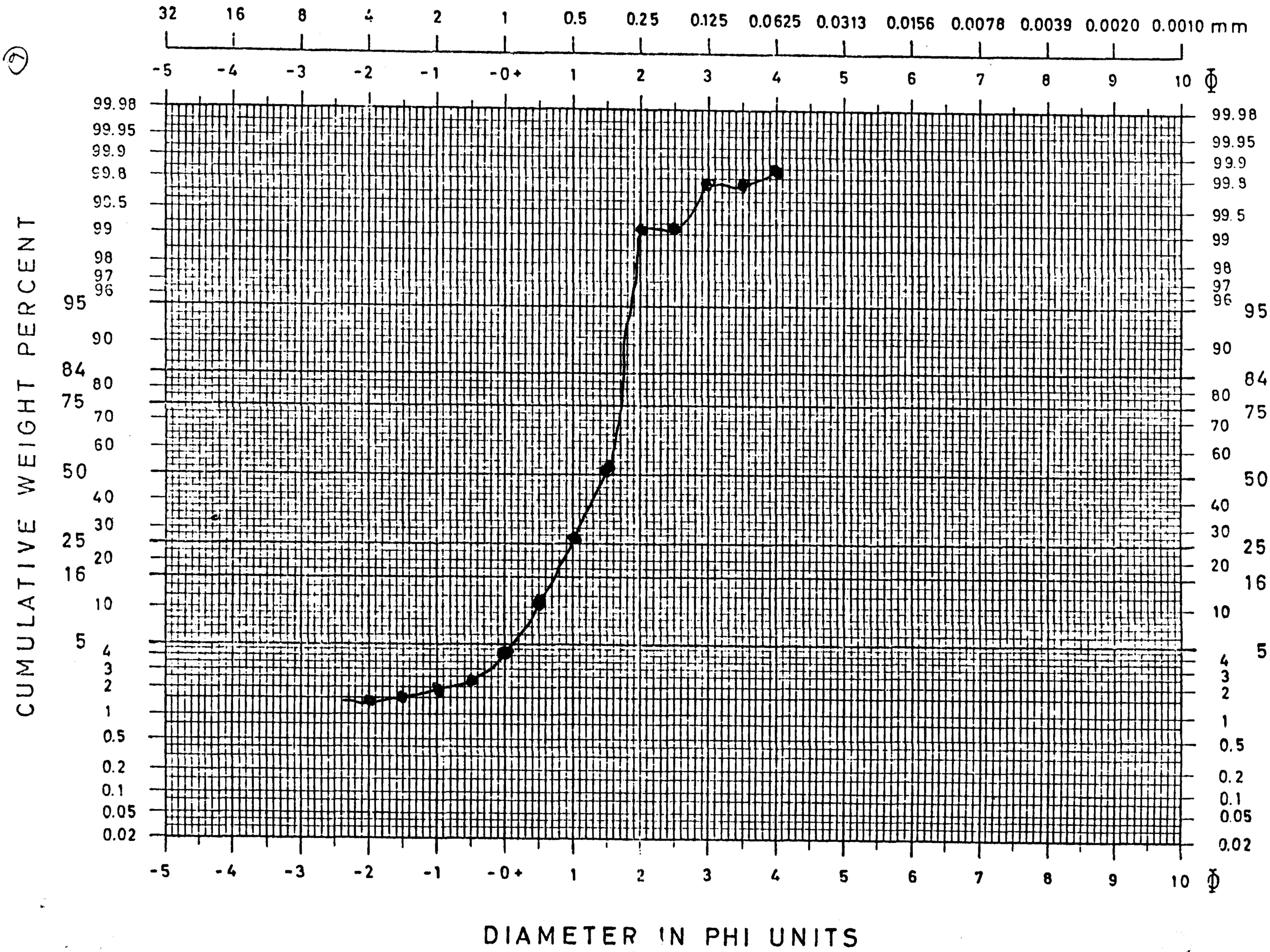
32 16 8 4 2 1 0.5 0.25 0.125 0.0625 0.0313 0.0156 0.0078 0.0039 0.0020 0.0010 mm
-5 -4 -3 -2 -1 -0+ 1 2 3 4 5 6 7 8 9 10 Φ
CUMULATIVE WEIGHT PERCENT
99.98 99.95 99.9 99.8 99.5 99 98 97 96 95 90 84 80 75 70 60 50 40 30 25 20 16 10 5 4 3 2 1 0.5 0.2 0.1 0.05 0.02
DIAMETER IN PHI UNITS

Diagram I

[illegible] = [illegible].26
F. Lev = 22.17
Sample = 86.69

REPORT ON SIEVE ANALYSIS

SAMPLE NO: 10
LOCALITY :

DATE: 5/21/88
ANALYST: M. Rouf

SIEVE MESH Mm.	Ø	Weight	Weight %	Cum. Weight	Cum.%
7.93	-3.00				
6.35	-2.75				
5.61	-2.5				
4.00	-2.0	0	0	0 0	0
2.83	-1.5	0.01	0.01	0.01	0.01
2.00	-1.0	0.03	0.03	0.04	0.04
1.41	-0.5	0.29	0.33	0.33	0.37
1.00	0.0	1.00	1.16	1.33	1.53
0.71	+0.5	3.95	4.50	5.26	6.03
0.50	+1.0	11.04	12.83	16.32	16.86
0.35	+1.5	23.68	27.52	40.00	46.38
0.25	+2.0	34.33	39.90	74.33	86.28
0.18	+2.5	11.59	13.47	85.92	99.75
0.13	+3.0	0.39	0.45	86.31	100.2
0.09	+3.5	0.03	0.03	86.34	100.23
0.06	+4.0	0.02	0.02	86.36	100.25
PAN		0.04	0.05	86.40	100.3
TOTAL			100.30	86.40	100.3

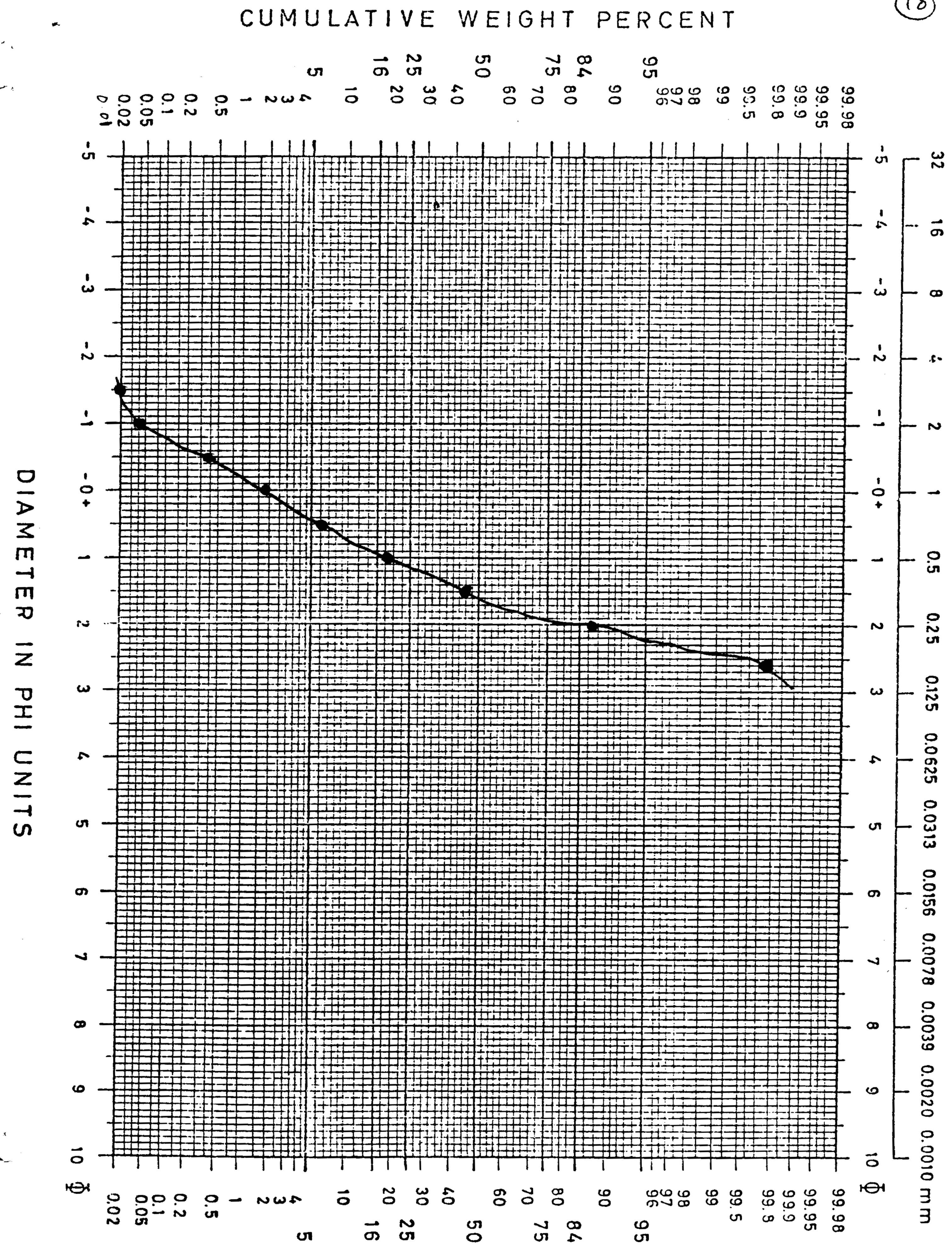
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS
0.01 0.02 0.05 0.1 0.2 0.5 1 2 3 4 5 10 16 20 25 30 40 50 60 70 75 80 84 90 95 96 97 98 99 99.5 99.8 99.9 99.95 99.98
-5 -4 -3 -2 -1 -0+ 1 2 3 4 5 6 7 8 9 10 Φ
32 16 8 4 2 1 0.5 0.25 0.125 0.0625 0.0313 0.0156 0.0078 0.0039 0.0020 0.0010 mm

Diagram I